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A review on wind power industry and corresponding insurance market in China: Current status and challenges

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ABSTRACT

China's wind power industry has achieved tremendous successes in recent years. The country's cumulative installed capacity has exceeded that of America and ranked first in the world. The fast development has also been accompanied by inevitable high risks. Wind turbine accidents are happening with increasing frequency. Since insurance is an effective measure and instrument to control risks, it can guarantee healthy development of the wind power industry. So the fast-growing wind power industry in China is in urgent need of insurance services. However, currently the slow-developing insurance does not match the fast-growing wind power industry. Up to now, there have been few correlative studies on such field. Therefore, based on the problems behind development of China's wind power industry, this paper emphasizes the importance of insurance for China's wind power industry, and also analyzes the challenges that China's wind energy insurance companies have to face. The aim of this paper is to let more experts know the status of both the wind power industry and its corresponding insurance market in China.

Contents

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1. Introduction

1.1. Overview of risks in wind energy industry

As a renewable source of energy, wind provides a significant contribution to renewable energy targets [1]. Wind turbines are extremely sophisticated machines. As wind speed changes, variations in the forces increase, resulting in exposure of wind turbines to severe risks [2,3]. Therefore, to help with decision-making all processes in wind energy industry should incorporate risk analysis [4]. According to the literature review, researches on risks in wind energy can be classified into the following categories:

1.1.1. Policy risk

Apart from financial supports, risks stemming from regulatory environments (legal security, administrative process and grid access) play a critical role in determining the attractiveness of development environments. Luthi [5] analyzed policy support instruments and regulatory risk factors for wind energy deployment. Carneiro [6] investigated possible societal risks associated with wind power generation systems.

1.1.2. Investment risk

For investors, project risks coexist with the long-term positive trend due to joint influence of several factors in the wind power industry, such as investment in construction, cost of operation, connection to grids, feed-in tariff and government subsidy. To assess investment risks of a wind power project. Yang [7] quantified wind energy investment risk premiums in an uncertain international energy policy context. Li [8] assessed the investment risk of wind power projects. Furthermore, Kitzing [9] identified the risk implications of two support instruments: feed-in tariffs and feed-in premiums.

1.1.3. Design risk

Design of wind turbine is characterized by high complexity and uncertainty. For efficient analysis and design, uncertainties need to be explicitly addressed, indicating the necessity for a risk-informed approach. Prostean [10] analyzed and identified the risk factors of a supply chain. González [11] presented a new methodology for designing a transmission system under risks. Taflanidis [12] proposed a simulation-based framework for quantification/evaluation of risks. Gabbar [13] presented a multidimensional modeling approach to evaluate risks based performance of smart grid infrastructures.

Undoubtedly, risks on components are also important. Dai [14] proposed a risk assessment on collisions between turbines and vessels. From the risk perspective, Chou [15] investigated for the first time the causes of collapse of a wind turbine tower in Taiwan. Sarajcev [16] presented a Monte Carlo procedure intended for assessing the failure risk of metal-oxide (MO) surge arresters on onshore wind farms. Nielsen [17] used a condition-based maintenance for the risk-based operation and maintenance of offshore wind turbine components.

Economic risks should also be taken into consideration in design stages. Hong [18] identified and evaluated the economic risks of tropical cyclones on offshore wind farms. Brennan [19] focused on methodologies to optimize life-cycle costs based on probabilistic risk approaches for offshore wind support structures.

1.1.4. Marketing risk

The most significant challenge for wind power production is uncertainty. In the market strategy of a wind power producer, uncertainty must be controlled in order to be profit-effective. Drake [20] used a risk portfolio approach in financial appraisals to measure potential reductions. Pousinho [21] proposed a stochastic programming approach for trading wind energy in a market environment under uncertainty. Mansour [22] proposed a multistage stochastic programming model to build optimal energy offers, which allowed wind power producer to properly compete in the electricity market.

1.1.5. Operation risk

Wind power production is intermittent and intrinsically dependent on the variability of wind speed [23,24]. Thus, large-scale integration of wind power brings new challenges and difficulties to operation of power systems. Moghaddam [25] presented a risk-averse profit-based optimal operation strategy for the optimal scheduling of a combined wind farm-cascade hydro system. Ghadikolaei [26] considered a practical methodology of risk measurement and management model to manage the risk of wind power generation. Similarly, Li [27] established a model for quantitative analysis of wind power operation and management risks. Furthermore, Gouveia [28] extended an existing probabilistic method for operational risk assessment of large-scale wind turbines. Montes [29] studied risk factors that had the greatest short-term impact on the economic viability of wind energy projects.

1.1.6. Ecological risk

The emerging development of wind energy has also raised public concern over its impact on ecology. Burger [30,31] and Christel [32] developed a conceptual model to examine possible wind energy risk to migrating shorebirds. Kikuchi [33] aimed to deduce a preliminary hypothesis and its formulation for the effect of offshore wind farm noise on fish. Hammar [34] applied Ecological Risk Assessment (ERA) on a wind farm project in Kattegat. Carrete [35] carried out a risk assessment of wind farms on population viability of a globally endangered long-lived raptor.

1.2. Purpose of this paper

Risks are a precondition for insurance. Should there be no risk, no loss will occur and thus no insurance is needed. Researches on risks are the basis for development of insurance [36]. The fledgling interest of insurance providers and risk managers in renewable energies is driven by several factors. The most important factor is that a range of relevant loss-prevention benefits are coming to light [37–43]. Among several renewable energies, wind energy serves as a fast growing alternative energy source which is clean and productive [44]. Insurance companies can play a part in a wind power industrial chain from raw materials required for upstream product manufacturing to downstream wind power services. As an effective means to guarantee healthy development of the wind power industry, insurance may mitigate risks in the wind power industry.

In Europe and North America where wind power is well developed, insurance has already been associated with the wind power industry. Risk management in wind power enterprises is becoming increasingly refined and professional. Foreign wind power enterprises are active in buying their insurance policies, while insurance companies communicate effectively and work closely with these enterprises to accomplish risk prevention, aversion and management to achieve a win–win result [45]. In sharp contrast to Europe and North America, China has a small and slow-developing wind energy insurance market. As China's wind power industry develops fast, problems are coming along. Since 2009, there have been increasing wind turbine failures in China; wind turbines after several years' operation have gradually manifested frequent failures [46].

In the long term, the wind power industry needs insurance to mitigate risks; the wind energy industry is also becoming a large emerging market for insurance companies. Association of the wind power industry with the insurance industry is a product of mutual needs in respective development, but the potential needs are still to be fully aroused. Therefore, this paper studies the wind power industry in China, analyzes the problems behind fast development of the wind power industry, investigates the current status of China's wind energy insurance market, and explores the challenges that insurance companies have to face.

This paper is structured as follows: In Section 2 we analyze the status and problem of China's wind power industry. Through analysis, we find that the wind power industry is in need of insurance. In Section 3 we firstly review risk assessment models for the wind power industry, which can be used as the basis of insurance. Even so, problems still exist in development of China's insurance market. Thus in Section 4 we analyze the development of wind energy insurance in China and in Section 5 investigate the problems and challenges for wind energy insurance providers. Conclusion and suggestions are provided in Section 6.

2. Status and problem

2.1. Competitive wind resources

With vast land and a long coastal line, China has abundant wind resources. As studies show, there is enormous potential wind power available in China, as shown in Fig. 1; the offshore and onshore wind resources to be developed in terms of installed capacity is up to about 700–1200 GW, or even reach up to 2500 GW according to the latest evaluation report [48]. Therefore, the wind power industry in China has a solid resource foundation that may support it to become a significant part in future energy structure of this country. As is known from a comparative analysis of the five top wind power countries, China has almost as much wind resources as America, much more than India, Germany and Spain.

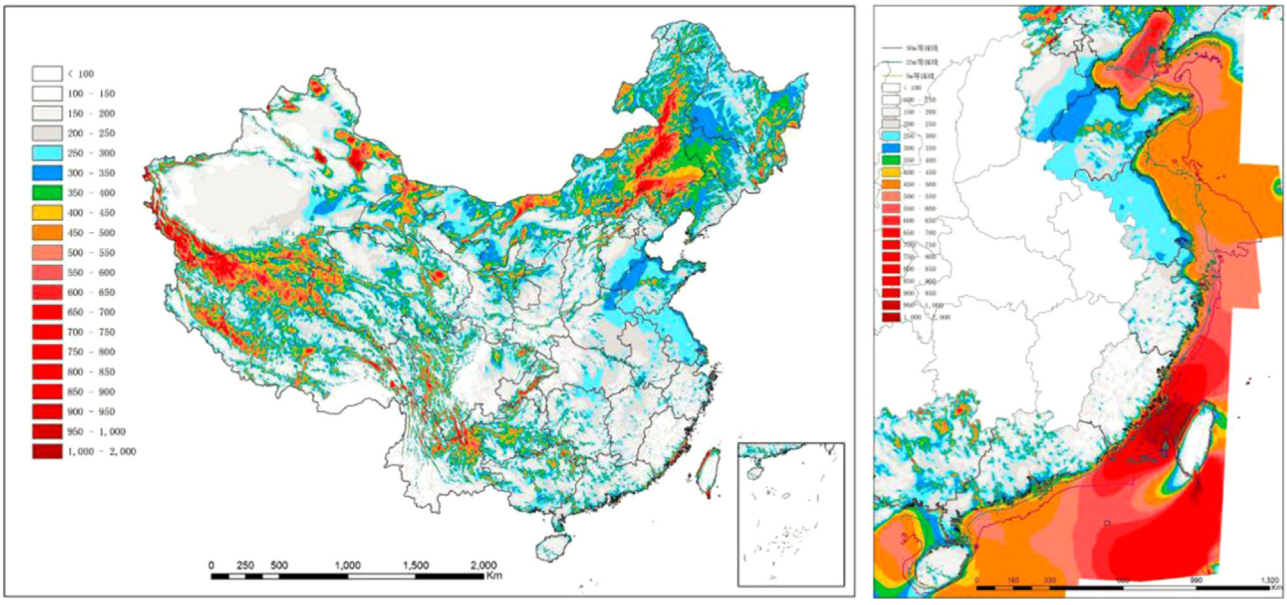

Fig. 1. Distribution of average wind power intensity in China (the left figure shows distribution of land-based wind resource potential (WPD ≥ 300 W/m^2, 70 m height; the right figure shows distribution of annual average wind power intensity at the height of 100 m in offshore areas with 5–50 m depth sea areas) .
Source: Energy Science & Technology in China: A Roadmap to 2050 [47].

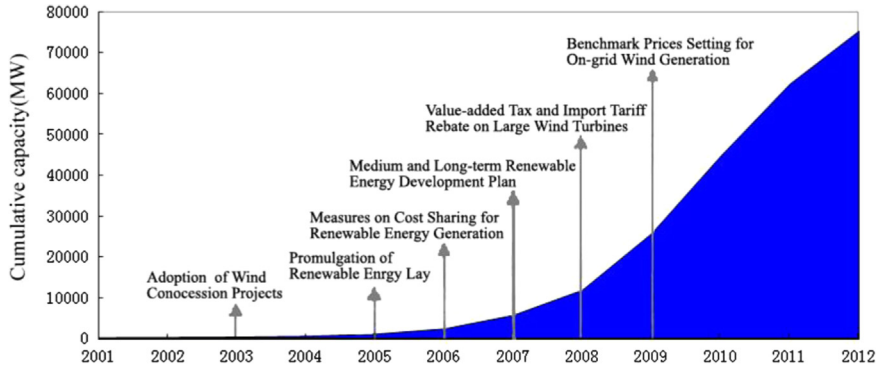

Fig. 2. Impacts of different policies on installed capacity of wind energy.
Source: Effective policies for renewable energy: the example of China's wind power lessons for China's photovoltaic power [50].

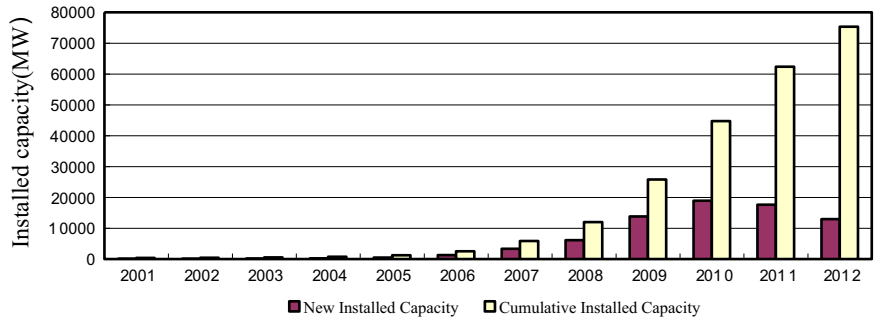

Fig. 3. New and cumulative installed capacity in China.
Source: Statistics on Wind Turbine Installed Capacity in China in 2012 [58].

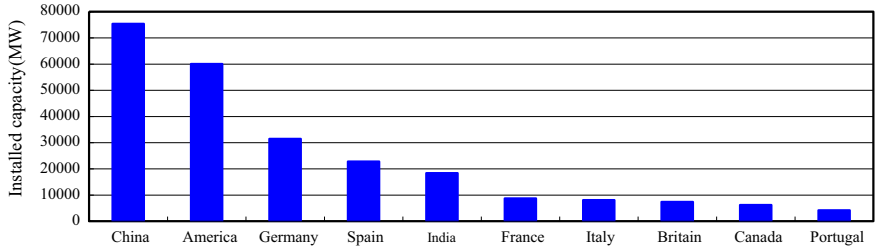

Fig. 4. Top ten countries in the world for installed capacity in 2012.
Source: REN21's Renewable Global Status Report [59].

2.2. Wind power achievements

Relying on the abundant wind resources, China has implemented a series of policies for developing the wind power industry (Fig. 2). In recent years, China's wind power industry has gained much support from the country, and achieved tremendous successes [49–56].

In China, wind turbines of domestic brands were virtually unknown in the domestic market before 2000. Since 2003, the country had organized five successive invitations to bid for national wind power concessions, allocating the right to construct wind power projects with an installed capacity of more than 3 GW. In 2005, GW-scale wind power bases were planned to be constructed; in 2008, ten GW-scale wind power bases were planned and constructed [57]. All these strongly pushed forward development of China's wind turbine industry, created sound market conditions for wind turbine manufacturers, stimulated development of the wind turbine manufacturing industry and advanced the formation of self-independent brands. Before 2005, only one Chinese wind turbine manufacturer ranked among the world top 10 [57]; in 2012, four ranked the world top 2, 7, 8 and 10, respectively. Sinovel, Goldwind, Mingyang and United Power were regarded as world-renowned wind turbine brands. China's wind turbine manufacturing industry was becoming even more mature. In 2012, among the top 20 wind turbine manufacturers, 17 were domestic manufacturers and 3 international manufacturers. The 17 domestic manufacturers contributed 90.45% to the increased installed capacity, while the 3 international manufacturers contributed 7.47% [58].

According to statistics from Chinese Wind Energy Association (CWEA), in 2012, 7872 wind turbines were newly installed in China (excluding Hong Kong, Macau and Taiwan), and the annual increase of installed capacity reached 12,960 MW. China's wind energy market entered a stable development stage after years' fast development. By late 2012, 53,764 wind turbines had been installed in China, with the cumulative installed capacity of 75,324.2 MW [58], as shown in Fig. 3. In 2012, China's wind power industry realized many breakthroughs: wind power generation contributed over 2% to the overall electric power for the first time;

wind power exceeded nuclear power for the first time and ranked the third among energy supplies in China.

In 2012, the top ten countries for cumulative wind power included China (75,324 MW), America (60,019 MW), Germany (31,460 MW), Spain (22,774 MW), India (18,384 MW), France (8,700 MW), Italy (8,037 MW), Britain (7,340 MW), Canada (6,165 MW) and Portugal (4,183 MW). China remained in the first place for its largest wind energy market [59], as shown in Fig. 4.

2.3. Problems behind rapid development

In the past several years, China's wind power industry has experienced fast development; however, the fast development has also brought unavoidable problems.

2.3.1. Intensified excess capacity

Currently, the total production capacity of wind turbines is far exceeding the domestic market demand, and is ill-adapted to development of the wind power industry in China [60]. The excess capacity is mainly resulted from expansion of large enterprises. There are two motivations for such expansion, i.e. competition and need for obtaining wind energy market resource. Only when the capacity was raised could the enterprises possibly take large orders and realize benefits of large-scale production, thereby acquiring a definite competitive advantage. Additionally, some large enterprises were compelled to construct plants in regions rich in wind resources due to local protectionism imposed by the so-called “resources-for-industry” policy, and then acquired orders based on the resources. The compelled and unreasonable expansion has brought about intensified excess capacity, which not only goes against the rules of scientific development, but also results in costly waste of social resources; meanwhile, the excess capacity also exposes the enterprises to operation risks [61].

2.3.2. Imperfect new technologies and concepts

By increasing investment in R&D, China has made bold innovations in wind energy. However, as the wind power industry started relatively late in China compared with foreign countries, preliminarily most Chinese manufacturers simply carried out production directly based on the drawings purchased from overseas. For this reason, to realize real innovations and breakthroughs by digesting and absorbing the introduced technologies required many fundamental researches, scientific experimentation and long-term accumulation of experience. Nevertheless, some newly developed technologies and concepts (such as large turbines, large blades, low wind speed, high-altitude wind turbine technology) had been put into hurried application, with insufficient consideration to possible risks [62].

Some manufacturers only pursue large wind turbines and new models which could be rapidly produced and mass installed, without attaching sufficient importance to digestion and absorption of imported technologies, innovation capability and quality of the products; they have not grasped the core technologies in aspects of integrated design of wind turbines, load optimization calculation, control strategy optimization and grid connection performance, resulting in unstable quality of some wind turbines and having caused many serious wind turbine quality incidents. All these have presented potential hazards to development of the wind power industry.

2.3.3. Vicious competition

The wind turbine manufacturing industry in China lacks self-regulation, and has no established competition standard. Most wind turbine manufacturers adopt irrational low-price strategies, resulting in over-competition [63]. In 2011, competition among wind turbine manufacturers became more fierce and chaotic, which was directly reflected by price competition – price of complete wind turbines dropping from 6200 Yuan/kW in 2008 to below 4000 Yuan/kW now. [50].

It is generally regarded that at such low prices for wind power equipment, it is hard to invest sufficiently in areas such as technological improvement and product quality guarantee. Meanwhile, price reductions have compressed profit margins of manufacturers and their investment in R&D of complete equipment and component, undoubtedly laying hidden risks for the wind power industry in the long term.

2.4. Wind turbine accidents

As the wind power industry grows fast, quality problems of wind turbines are also coming along. Wind turbines introduced to the market earlier have undergone several years' operation and gradually manifested frequent failures; disadvantages of fast development in recent years have gradually emerged [61]. As from 2009, tower collapses, blade breakage, cabin fires, electric shocks and other engineering accidents have caused injuries and deaths of cumulatively over ten persons and destroy of dozens of wind power equipments. Wind turbine accidents are becoming a global

Fig. 5. Wind turbine burning accident.
Source: [64].

Fig. 6. Wind turbine collapse accident.
Source: [64].

Table 1
Wind turbine accidents in China in recent years.
Source: Reports on Domestic Wind Turbine Accidents in Recent Years [65].

Time	Manufacturer	Place	Description of accident
02/2010	Sinovel Wind Group Co., Ltd.	GD Power Ninghai Wind Farm, Ninghai Zhejiang Province	Two 1.5 MW wind turbines burned and collapsed
08/2010		CPI Jiuquan Wind Farm, Gansu Province	A 1.5 MW wind turbine collapsed
01/2011		Chahar in Shangyi County, Hebei Province	A 1.5 MW wind turbine touched a 35 kV high-voltage line during installation, causing three deaths due to electric shock
03/2011		Huaneng Fuxin Wind Farm, Liaoning Province	A 1.5 MW wind turbine burned
03/2011		Huadian Yihetala Wind Farm, Inner Mongolia	A 1.5 MW wind turbine burned
03/2011		Jiuquan Industrial Park, Gansu Province	A vehicle carrying a 5 MW wind turbine base experienced a brake failure, causing two deaths
04/2011		Hongshan, Gansu Province	A 1.5 MW wind turbine burned
10/2011		Jiuquan Industrial Park, Gansu Province	A crane broke and collapsed during a test run of a 5 MW wind turbine; in the accident, 5 persons died and 1 was injured
10/2011		Zhangbei County, Hebei Province	A 3 MW wind turbine burned
07/2009	Wind Power Division of Dongfeng Turbine Co., Ltd.	Bayinxile Town, Inner Mongolia	A 1.5 MW wind turbine burned and collapsed
01/2010		Tongliao City, Inner Mongolia	A 1.5 MW wind turbine experienced breakage of its back bearing that triggered the safety chain and resulted in runaway, collapse and burning of the turbine
02/2010		Tianjing Wind Farm, Ningxia Province	A 1.5 MW wind turbine had the blade break, causing the wind turbine to burn and collapse
07/2010		CGN Daan Wind Farm, Jilin Province	A 1.5 MW wind turbine collapsed
02/2011		SE Tongliao Wind Farm, Inner Mongolia	A 1.5 MW wind turbine burned
04/2011		CGN Guazhou Wind Farm, Jiuquan City, Gansu Province	A 1.5 MW wind turbine burned
06/2011		CGN Daan Wind Farm, Jilin Province	A 1.5 MW wind turbine burned
10/2010	Guodian United Power Technology Co., Ltd.	Longyuan Wind Farm in Kangping, Liaoning Province	A 1.5 MW wind turbine collapsed
09/2010	Zhejiang Windey Co., Ltd.	Danjinghe Project of China Energy Conservation and Environmental Protection Group	A 1.5 MW wind turbine collapsed
11/2011		Zhangbei Area, Hebei Province	A 750 KW wind turbine collapsed
02/2010	Jiangsu Xinteng Wind Power Equipment Co., Ltd.	Datang International Wind Farm in Zuoyun County, Shanxi Province	Two 1.5 MW wind turbines collapsed
11/2009	Vestas	Mintou Project, Fujian Province	Two 850 KW wind turbines burned
01/2012		Tianfeng Project in Dabancheng, Xinjiang Province	A 750 KW wind turbine collapsed
03/2009	Gamesa	Tongyu County, Jilin Province	An 850 KW wind turbine collapsed due to failure of the foundation
04/2009		CGN Northeast Project	An 850 KW wind turbine the blade burned due to over speed
04/2009		Changdao County, Shandong Province	An 850 KW wind turbine burned
12/2009		Longyuan Denglonghe Wind Farm, Chifeng City, Inner Mongolia	A 2 MW wind turbine burned
04/2010	Suzlon	Jingneng Zhuozishan Project, Inner Mongolia	A 2 MW wind turbine burned
07/2011	GE	Dongling Longyuan Project, Jiangsu Province	A 2 MW wind turbine burned
10/2011	Guangdong Mingyang Wind Power Industrial Group Co., Ltd.	SE Manzhouli Project	A 1.5 MW wind turbine collapsed; 1 person died, and 3 persons suffered serious injuries
12/2011		Huaneng Yudaokou Wind Farm, Hebei Province	A 1.5 MW suffered galloping and collapsed
09/2012		Huaneng Toksun Project Phase III, Xinjiang Province	A 1.5 MW wind turbine collapsed; in the accident 2 persons died and 1 was injured
10/2011	Zhejiang Huayi Wind Energy Co., Ltd.	Ulanqab Wind Power Project, Inner Mongolia	A 1.5 MW wind turbine collapsed to break the collector route, causing disconnection of all wind turbines from the grid
02/2012	Wind Power Division of CSR Zhuzhou Institute Co., Ltd.	Tongliao City, Inner Mongolia	A 1.5 MW wind turbine burned, causing 2 deaths

concern. See Figs. 5 and 6. Disadvantageous to wind turbine manufacturers and developers, wind turbine accidents are often kept confidential to avoid adverse effect. We have tried to collect as much information as possible via the Internet and other channels to be presented here [64,65]. See Table 1.

2.5. Involvement of insurance

In China, the fast-growing wind power industry is accompanied by high risks. As Shi Lishan [66], Deputy Director of Energy Division of the National Energy Administration said when summarizing the development of China's wind power industry, "2011 was an extraordinary year for development of China's wind power industry. We experienced great changes in the wind energy industry. Through the three years' fast development, the wind power industry has gained remarkable achievements. Meanwhile, there are also many new conflicts and problems. Various accidents have been occurring during operation, including disconnection from the grid in a large area, accidents occurring during construction, burning and collapse of wind turbines, etc. It can be seen that there are indeed serious problems emerging in development of the wind power industry [67]".

Therefore, it is necessary to stress effective risk control of the wind power industry. Risk control of the wind power enterprises may include daily maintenance and management, or otherwise by insurance. Since insurance is an effective measure and instrument to control risks, it can provide a specific solution to compensation for economic loss, and can be a critical support to guarantee healthy development of the wind power industry. Insurance companies can play a part in the wind power industrial chain from raw materials required for upstream product manufacturing to downstream wind power services. As an effective instrument to guarantee healthy development of the wind power industry, insurance may mitigate risks occurring in the industry [68].

3. Risk models for the wind power industry

Relevant insurance theories are critical for associating insurance with the wind power industry in China. According to the literature review, typical risk models in the wind power industry can be classified into the following five categories, which can serve as the basis of wind energy insurance.

3.1. Risk model for investment

Based on complete consideration of various risk factors (viewed as random variables) for investment returns of wind power projects [8], the Monte Carlo simulation method is employed to calculate the NPV and evaluate the TD and IRR of the projects, so as to eventually analyze the investment risk. Detailed procedures are provided as following [69–72].

Step 1 Calculate the net present value (NPV).
Step 2 Estimate the wind velocity (v) and annual total generated electricity (G_i).
Step 3 Estimate the investment in a construction period.
Step 4 Estimate the annual total cost (TC_i) and average operation cost (OC_i) in an operation period.
Step 5 Determine the carbon equivalent transaction price (P_c) and baseline emission factor (EF_i).
Step 6 Monte Carlo simulations.
Step 7 Analyze the T_D and IRR.

3.2. Risk model for a wind power supply chain

The investment in wind power projects requires a deep understanding of various risks in the supply chain [10]. To find out risk factors in the wind power supply chain, the Analytic Hierarchy Process (AHP) method can be used. The decision hierarchy is a graphical representation of the decision goal, the main objectives, the risk factors (attributes) and the alternatives, as shown in Fig. 7.

While the results provided in Fig. 7 offer interesting and useful information, the main goal of the AHP evaluation is to determine which alternative can produce higher risks, from the part of the supplier contracted through public procurement, for the research team to identify maximum sources of the risks in order to achieve final implementation of the project in safe conditions. A formal data collection process is necessary for the evaluation of the risk factors. Based on AHP [73–76], risk factors in the supply chain can be identified [77], as shown in Table 2.

3.3. Risk model for wind turbine structures under extreme conditions

Design and operation of wind turbines are characterized by high complexity and uncertainty due to extensive variability of components, intense interaction among components and assemblies, multiple uncertain loading sources and different operation conditions [12]. For efficient analysis and design, uncertainties

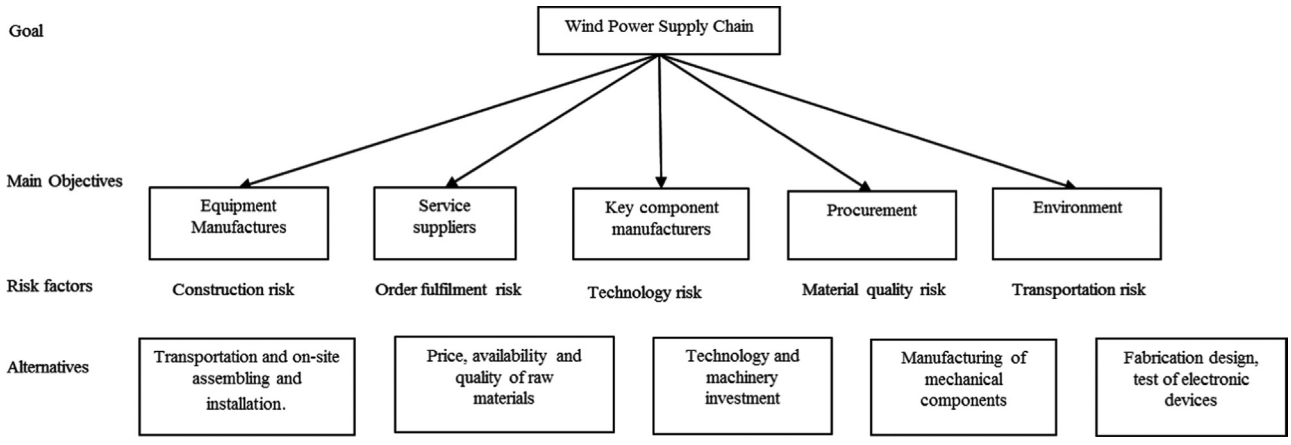

Fig. 7. Framework for assessing risk factors in a wind power supply chain.
Source: Risk variables in a wind power supply chain [10].

Table 2
Final weights of alternatives across risk factors.
Source: Risk variables in a wind power supply chain [10].

Risk factor	Alternatives				
	Transportation and on-side assembling and installation	Price, availability and quality of raw materials	Technology and machinery investment	Manufacturing of mechanical components	Fabrication design, test of electronic devices
Construction risk	0.353	0.104	0.180	0.224	0.137
Receivable risk	0.312	0.094	0.194	0.208	0.190
Guaranty risk	0.322	0.244	0.140	0.185	0.106
Order fulfillment risk	0.208	0.194	0.190	0.094	0.312
Logistic risk	0.322	0.140	0.106	0.185	0.244
Delay risk	0.251	0.241	0.209	0.156	0.141
Technology risk	0.295	0.147	0.182	0.189	0.147
Outsourcing risk	0.179	0.209	0.211	0.249	0.149
Material quality risk	0.214	0.242	0.210	0.142	0.189
Demand risk	0.244	0.153	0.190	0.196	0.214
Transportation risk	0.314	0.194	0.194	0.102	0.194
Disruption risk	0.205	0.258	0.246	0.099	0.189
Man-made risk	0.198	0.200	0.187	0.191	0.222

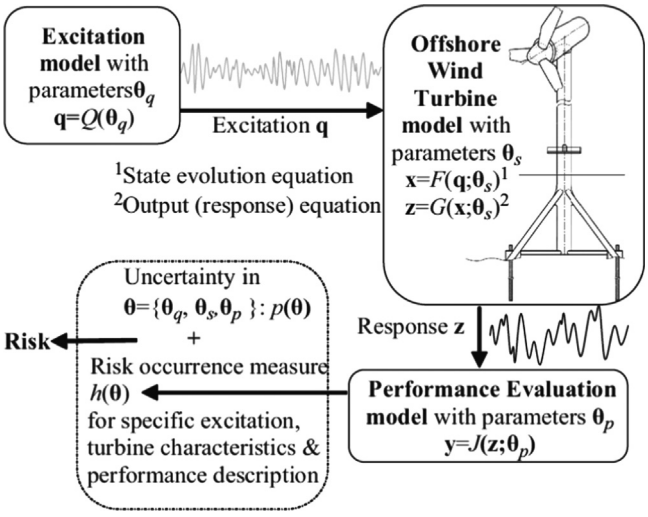

Fig. 8. Risk quantification framework.
Source: Risk quantification/evaluation of offshore wind turbines under extreme environmental conditions [12].

need to be explicitly addressed, indicating the necessity for a risk-informed approach. Simulation-based probabilistic techniques offer a powerful tool for quantification/evaluation of wind turbine risks, as shown in Figs. 8 and 9. Based on such thoughts [78–81], the versatility and computational efficiency of the advocated approaches are finally exploited to support development of standalone risk assessment applets for automated implementation of probabilistic risk quantification/assessment.

3.4. Risk model for operation and management

According to the analysis of wind power operation and management in China, two major problems exist [27]. One is related to the feed in tariff, the other concerns the grid electricity from wind power. Both are closely related to operation and management of wind turbines [82–89].

The risk analysis model of wind power feed-in tariff is given by

$$R_P^r = \frac{[(r+\Delta r)(1+r+\Delta r)^n][(1+r)^n-1]-r(1+r)[(1+r+\Delta r)^n-1]}{[(1+r+\Delta r)^n-1]} \tag{1}$$

where r is discount rate and n is depreciation period. Eq. (1) indicates that r is an important manifestation of the national policy and a guide for development of the wind power industry, which will clearly affect the wind power feed-in tariff.

The quantitative risk analysis model of wind power generation delivered to the grid is given by

$$R_{On\_grid} = [T(1-\lambda)r_A]^2\{E[P^2(\upsilon)-(E[P(\upsilon)]^2)]\}$$
$$= [T(1-\lambda)r_A]^2\left\{\int_0^{+\infty} P^2(\upsilon)f(\upsilon)d\upsilon - \left[\int_0^{+\infty} P(\upsilon)f(\upsilon)d\upsilon\right]^2\right\} \tag{2}$$

where T is the operation time of the wind turbine, υ denotes the wind speed, $f(\upsilon)$ the probability density function, r_A is the wind power acceptance rate of the regional grid, and λ is the station service power consumption rate. $P(\upsilon)$ indicates the output of the wind turbine. From Eq. (2), we can conclude that the risk of the wind power delivered to the grid is related to the wind speed, the power characteristics of the wind turbine, the station service power consumption rate, and the wind power acceptance rate of the regional power grid. Therefore, risk control measures can be conducted from these four aspects.

3.5. Risk model for marketing

The conditional value-at-risk (CVaR) [90–92] was incorporated in the model to consider the risk associated with the volatility of the profit in the wind producer problem. In this case, the CVaR is useful for limiting the probability of experiencing a low profit in unfavorable scenarios. The conditional value-at-risk at α confidence level, α-CVaR, is approximately equal to the expected profit of the $(1-\alpha)$ 100% scenarios with the lowest profit. The CVaR is also known as mean excess loss or average value-at-risk. Mathematically, the CVaR (α, x) for a discrete distribution is defined as, [93,94],

$$CVaR(\alpha,x) = \left(\zeta - \frac{1}{1-\alpha}\max(\zeta - f(x,n,m),0),0\right) \le \alpha \le 1 \tag{3}$$

$$s(m,n) = \max(\zeta - f(x,n,m),0) \tag{4}$$

or

$$s(m,n) \ge (\zeta - f(x,n,m), s(m,n) \ge 0 \tag{5}$$

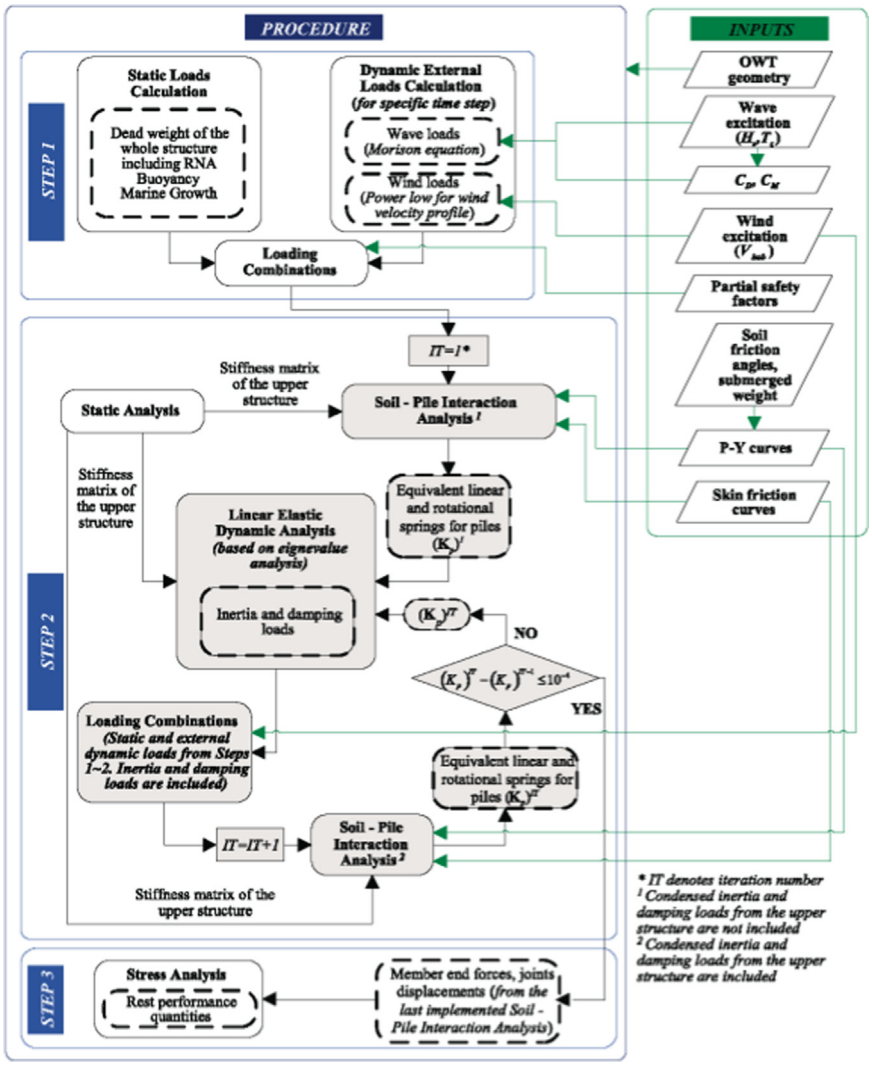

Fig. 9. Structural analysis process in a high fidelity structural model.
Source: Risk quantification/evaluation of offshore wind turbines under extreme environmental conditions [12].

where $f(x,n,m)$ is a profit function in the scenario (m,n). The optimal value of ζ is the greatest value of the profit such that the probability of the actual profit being smaller than or equal to f is less than or equal to $1-\alpha$. The variables $s(m,n)$ is equal to the difference between g and the $f(x,n,m)$ (profit in scenario (n,m)) if this difference is positive, being 0 otherwise.

4. Development of wind energy insurance in China

Though there are risk analysis models, it is still a long way for China's wind energy insurance industry to go. In Europe and North America where wind power technologies and products are relatively mature, insurance is closely associated with the wind power industry, and insurance products cover many industrial procedures, while in China, compared with the fast-developing wind power industry, wind energy insurance develops relatively slow, and can be generally classified into the following stages [95], see Fig. 10.

4.1. Preliminary stage (1986–1993)

At this stage, the wind energy market mainly developed by utilizing foreign donations to construct small-scale pilot wind farms; governments mainly supported financially, such as investment in research and manufacture of wind turbines. At this stage, wind energy insurances mainly covered cargo transportation and property losses. Meanwhile, the insurance objects were scattered, featuring small amounts and small scales. Insurance companies accepted insurance completely based on their experience in similar domestic electromechanical equipments and partial experience from overseas. It was generally the preliminary trial stage of the wind energy insurance industry.

4.2. Industrialization stage (1994–2003)

At this stage, the wind energy market experienced from fast development to slow development. Connection of wind power to grids had been well developed due to a series of measures, including approval for nearby electric power companies to uniformly acquire power from wind farms in 1994, loans for technical improvement to realize faster development in 1996 and 1998 respectively, and a series of incentive policies in *National Debt for Wind Power Project* in 2000. However, during the process of reform in electric power system, due to high cost and uncertain policies, the growth rate tended to slow down. The wind energy insurance industry also experienced the same process. Upon early development of the wind power industry, insurance companies regarded it

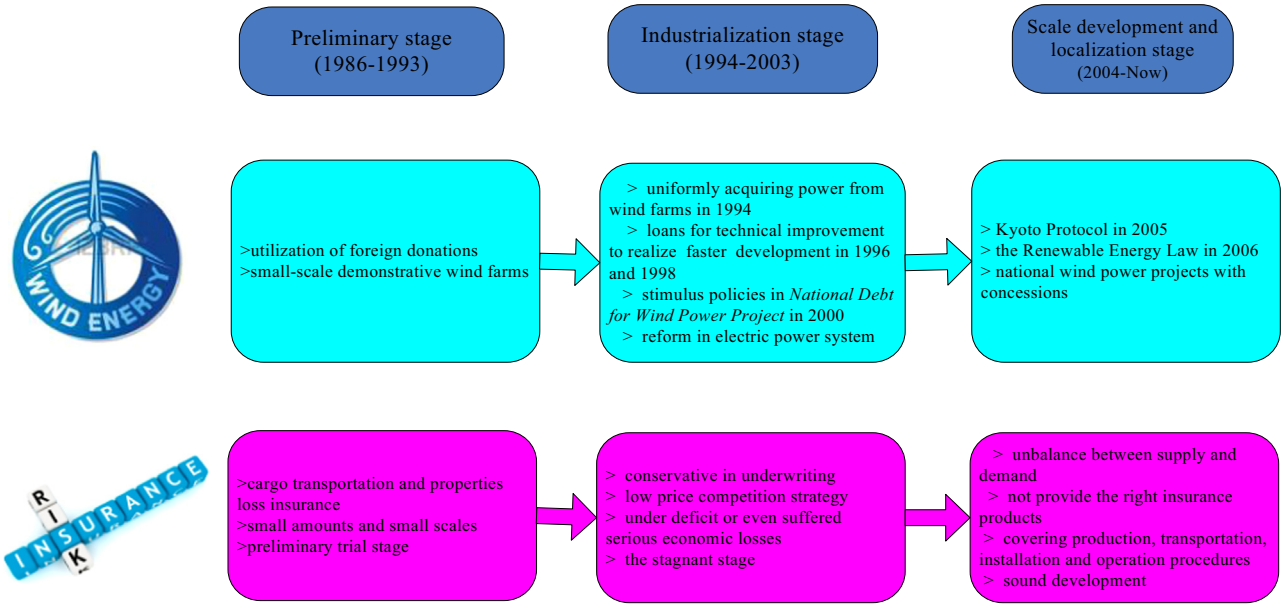

Fig. 10. Development of wind energy insurance in China.
Source: Development History of Wind Energy Insurance [95].

as an emerging business, and thus were conservative in underwriting. Consequently, clients had few choices, and development of wind energy insurance was also restricted. Along with development of the wind power industry, reform of the wind energy insurance industry was also deepened. As more competitors engaged in the wind energy insurance industry, plus no historical underwriting data and relevant experience, insurance companies adopted a low price competition strategy to seize the emerging market, resulting in more focus on price than on risks in the market. Furthermore, latest R&D projects were put into volume production. With less mature technology and unstable reliability, accidents of turbines happened with increasing frequency. Therefore, insurance companies which had underwritten wind turbines were generally under deficit or even suffered serious economic losses. Consequences of irrational competition not only made the insurance companies more cautious in underwriting or even withdrawing from the market, but also triggered unwillingness of the wind turbine enterprises to take out insurances due to hard underwriting, long period of claim and high costs. All these brought the wind turbine insurance market gradually into a stagnant stage.

4.3. Scale development and localization stage (2004 up to now)

Climate changes pushed forward further development of wind energy technologies. The wind power industry gained unprecedented development. With formal execution of the Kyoto Protocol in 2005 and the Renewable Energy Law in 2006, the country encouraged a series of wind power projects with concessions, having facilitated fast development of the wind energy market. At this stage, wind power enterprises had increasing demands for commercial insurance; wind farm owners were required to take out insurance packages for wind power projects with concessions. However, at this stage, insurance companies had not kept a watchful eye on new demands of the wind energy market, but still employed traditional practices, resulting in unbalance between supply and demand in the wind energy insurance market. Consequently, due to unfamiliarity with the insurance market, wind power enterprises failed to give enough consideration to costs and demand upon selecting insurance products; due to unfamiliarity with the wind power industry, insurance companies could not provide right insurance products.

Nevertheless, guided by the rigid demands from the wind power industry, insurance companies have made efforts to provide wind energy insurance products covering production, transportation, installation and operation procedures in the wind power industry. This insurance market is turning to sound development.

5. Challenges for wind energy insurance in China

As the wind power industry in China develops fast, corresponding insurance market emerges but develops slow, mainly due to the following reasons:

5.1. Lacking effective mechanism

In Europe and North America, project financing is a major means for wind power enterprises to get funds. Meanwhile, insurance companies and banks play a significant role in project financing. Under circumstances where investment returns are directly associated with project income, investors will actively seek for necessary measures to lessen and control risks. Investors prefer wind energy projects that have been insured, and sometimes will even actively ask the project owners to take out insurances. Project financing has boosted development of the wind energy insurance industry.

In China, major wind energy developers are state-owned electric power groups or energy companies, while banks are one of the main channels for them to get funds. However, banks generally do not approve grants of loans to single projects, but directly accredit groups or parent companies for their capability of repaying loans. In such situation, banks will not evaluate risks and profit or loss of single projects in detail, nor consider whether the projects will have the risks lessened by insurance [46,68]. Therefore, such an important factor is missing in development of the wind energy insurance in China.

5.2. Potential risks

Early in 1950s, China had started R&D of wind energy. However, scale development of the wind power industry was realized in 2006. According to statistics from the Chinese Wind Energy Association (CWEA), the installed capacity of wind energy in China has increased by dozens of times in just several years to a level equivalent to that of the European wind power industry in 30 years. However, the wind power industry also exposed the insurance companies to new challenges and risks.

Although the installed capacity of wind energy in China has exceeded that in Europe and North America, the wind power industry of China is still at the preliminary stage of scale development, and there is still a gap in aspects of technological level and product quality, compared with the foreign countries. According to statistics from CWEA, since the first domestically manufactured MW-scale wind turbine came off line, about 28 enterprises have realized volume production [45]. Nevertheless, wind energy technologies are mainly originated from Europe, and designs are based on IEC 61400 standards which have been formulated based on environmental conditions in Europe. Whether the standards are applicable to China is still to be validated. Additionally, the quality control levels of equipment manufacturers in China have also led to potential quality problems of wind turbines under operation, and thus insurance companies are unwilling to rush into the wind energy insurance market. At present, most wind turbines in China have been in service for no more than five years; various wind power equipment failures, which ever appeared in Europe and North America [96,97], have not been fully exposed in China, particularly risks of batch equipment failures. For insurance companies, the biggest risk is unknown risk. China is just in a situation in which Europe was [46,68]. Besides, through five years' fast development, the wind power manufacturing industry in China is experiencing fierce competition. According to statistics from CWEA in 2008, a 1.5 MW wind turbine was quoted about 600 pounds per kilowatt (equivalent to 6200 Yuan per kilowatt); in 2013, the price dropped to about 400 pounds per kilowatt (equivalent to 4000 Yuan per kilowatt) [98]. It was generally recognized that sharp drop of prices would possibly affect the wind turbine quality, which thus hindered the entry of insurance companies into the wind power industry.

5.3. Low Profitability

At present, auto insurance is still a primary market that the insurance companies are competing for in China; insurance companies also have greater focus on the auto market than the wind energy market. In the current wind energy insurance market, the premium rate is 0.5–1.5‰ for the enterprise property insurance, 0.8–1.5‰ for the machinery breakdown insurance and 0.35–0.65‰ for cargo transportation insurance. Compared with the average premium rate for wind energy insurance in Europe (about 7‰), the premium rate in China is lower, and does not match the high risks of the wind power industry.

According to the past underwriting data, there were some insurance companies trying to formulate premium rate terms, but the premium rates obtained through calculation after taking into consideration various factors were about ten times greater than those in actual transactions [46]. This suggested that insurance companies had to undertake extremely high risks for underwriting wind turbines, and would compensate much more than corresponding premium income once any wind turbine accident occurred. For example, if an insurance company underwrote a wind farm with 33 sets of 1.5 MW wind turbines for the enterprise property insurance and machinery breakdown insurance, the annual premium income of the insurance company was only 39,000–118,000 pounds (about 400,000–1,200,000 Yuan), but if a serious gearbox failure occurred, the total cost of restoring the items would exceed 100,000 pounds (about 1,000,000 Yuan). Due to the high risks and great compensation, most insurance companies engaged in this business are under deficit or at low profit status [69].

Under such situation, it is hard for insurance companies to pay great amount of capital for risk survey in the wind power industry, seeking for loss prevention advice and developing insurance products. The wind energy insurance industry in China has lagged significantly behind the fast growing wind power industry.

5.4. Lacking underwriting data and experience

As shown in Fig. 11, due to lack of long-time operation and failure data of wind power equipments, insurance companies can hardly know the loss and compensation conditions of wind energy projects, and thus mass application of insurance in the wind energy field has been hindered [46,68]. Although some insurance companies in China had been involved in the wind energy field for over 10 years, most insurance companies began to pay attention to wind energy insurance in 2006, and simultaneously accumulated relevant data in this field.

As industrial risks and loss rate are gradually growing with development of the wind energy industry in China, it is hard for insurance companies to accurately position, quantify and rate the risk probability and degree of damage based on less than five years' claim data and experience. Besides, lack of long-term underwriting data and experience also hinders the insurance companies developing insurance products. Currently, most insurance products in China are developed in reference to similar products of foreign insurance companies or designed based on experiences in the same products applied in other industries; these insurance products cannot fully cover the risks and losses occurring in the wind energy industry in China, and there are always some deviations.

5.5. Lacking correct recognition of the role and value of insurance

Currently, some wind power enterprises are unaware of the importance of insurance. On one hand, the enterprises focus more on manufacturing and marketing, without giving much consideration to insurance for lessening risks. On the other hand, the enterprises generally take out the enterprise property insurance, construction and installation engineering insurance, cargo transportation insurance, machinery breakdown insurance and other traditional insurance products, while ignoring the product quality bond insurance, business interruption insurance and other types of important insurances. Thus risks in the wind energy industry cannot be fully covered [46,68]. Due to inadequate recognition of the insurance, enterprises take it for granted that insurance companies should compensate for all losses incurred. But actually risks and losses not covered by the insurance contract are to be assumed by the enterprises themselves, other than those compensated by the insurance companies.

Additionally, the first choice for Chinese wind farm developers to control the quality risks of wind power equipments is not insurance, but extension of the warranty period (from 2 years at the very beginning to the current 3–5 years), so that the risks are transferred to the equipment manufacturers. Under the situation where the price battles between wind power equipments become fiercer and the warranty period become longer, the wind power equipment manufacturers undoubtedly suffer greater pressure. This is a disadvantage to healthy development of the wind power manufacturing industry and also adverse to its corresponding insurance industry.

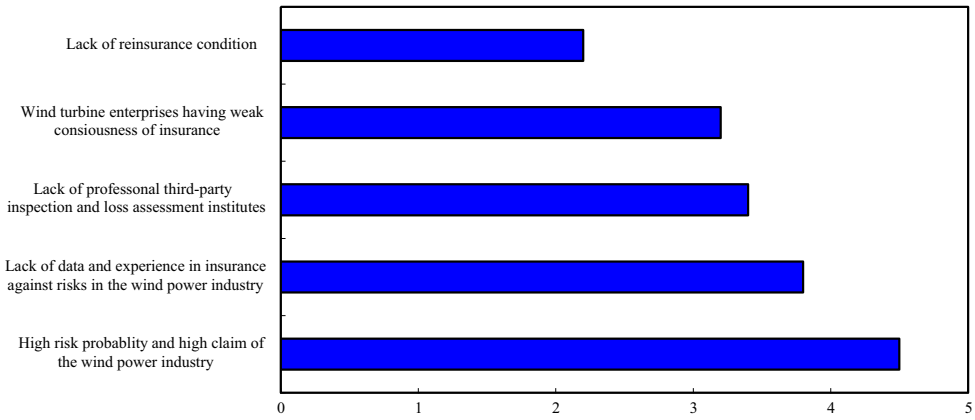

Fig. 11. Major factors impacting on insurance companies for insuring the wind power industry.
Source: Current Situation of Wind Energy Insurance and Challenges in China [46].

6. Conclusion and suggestions

Association of the wind power industry with the insurance industry is required by the development of both industries. However, the wind power enterprises have conservative ideas about insurance and lack correct recognition of the role and value of insurance; meanwhile, insurance companies have inadequate confidence in the emerging wind power industry. Consequently, healthy development of wind energy in China is adversely affected. This paper analyzes the challenges the wind energy insurance industry had to face, aiming to let more experts know the status of both the wind energy industry and its corresponding insurance in China, so that they may give better suggestions for healthy development of China's wind power industry.

Through this paper, we suggest that wind power enterprises shall be more aware of risk control, correctly recognize the role and value of insurance, adopt measures to reduce industrial risks and increase insurance companies' confidence, establish third-party organizations for wind power equipment maintenance and service; meanwhile, the insurance industry shall promote awareness of risk management, guide wind power enterprises in execution of risk control, perfect terms of insurance contracts, improve the insurance service quality, facilitate capacity building, and actively cooperate with third-party organizations.

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